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Mejora del rendimiento térmico de los edificios históricos "difíciles de tratar" en el centro de Edimburgo

Improving The Thermal Performance of "Hard-to-Treat" Historic Buildings in Edinburgh's New Town

Julio Bros Williamson[a], Jon Stinson[a], Alasdair Reid[a] & John Currie[a]

[a] Edinburgh Napier University, Scotland. 42 Colinton Road, Edinburgh, EH10 5BT

***Resumen*— Compuestos alternativos en el sector de la envolvente se obtienen por extrusión de estirado de secciones y perfiles de panel de enclavamiento estrechas. Estos elementos estructurales, resistentes al impacto, tienen la ventaja de una instalación más rápida y segura, y su diseño modular les hace idóneos para muchos edificios y otras aplicaciones. Un desarrollo adicional en esta área puede ser la obtención de una alternativa sostenible a los perfiles compuestos actuales. Estudios anteriores han demostrado que los compuestos fabricados a partir de materiales naturales tales como fibras y polímeros bio-derivados, ofrecen una alternativa sostenible a los polímeros y materiales compuestos tradicionales. El objetivo de este desarrollo es reemplazar el típico perfil de acero ligero. Los perfiles de acabado también se pueden utilizar para terminar tabiques de mampostería existentes, revestimiento de ejes mecánicos y de extracción y revestimiento de la columna. Los perfiles se han diseñado utilizando bio-polímeros, reforzados con fibras naturales. Se han establecido los parámetros de procesamiento y las formulaciones apropiadas de bioresina y fibras naturales. También se ha evaluado la adaptación de las técnicas de procesamiento de pultrusión existentes a las características concretas de los nuevos biomateriales y fibras naturales. Como resultado, los perfiles de pultrusión adaptados a la construcción se han desarrollado con la incorporación de nuevos materiales y biomateriales basados en resina.**

Palabras clave— Biomateriales compuestos; fibras naturales; pultrusión; perfiles; envolvente del edificio.

***Abstract*— This paper documents an innovative partnership project between Historic Scotland, the Scottish Energy Centre at Edinburgh Napier University and Castle Rock Edinvar Housing Association in which five Category B Listed, traditional pre-1919, solid wall 'hard-to-treat' residential tenement properties located within Edinburgh's historic UNESCO World Heritage site each received energy efficient upgrades to walls and windows. A variety of measures were tested, achieving significant reductions in fabric heat loss without impacting upon the character and appearance of the buildings. The project is significant in that the energy-efficient upgrades all met with strict conservation requirements on alterations to Listed Buildings and have the potential to be replicated in similar properties throughout Scotland. The project won the award for best refurbishment project at the Carbon Trust's Low Carbon Building Awards in 2012. All of the properties featured in this study are occupied by tenants within the social-rented sector who prior to the study had indicated some thermal discomfort due to poor window conditions and high heat loss through walls causing increase fuel consumption. The occupants all remained in their homes during the refurbishment activities.**

Index Terms— Energy efficiency; conservation; refurbishment; historic buildings.

I. Introduction

With an estimated 80% of the UKs 2050 housing stock having already been built, it is clear that efforts to reduce carbon emissions from this sector must focus on the energy-efficient retrofit of the existing stock (Boardman, 2007).

Figure 1 shows the composition of the housing stock in Scotland, in terms of age and dwelling type. The Scottish House Condition Survey (2013) reveals that there are 2,402,000 occupied dwellings in Scotland. From this total, 204,000 (8%) are tenements that were constructed before 1919 – an important turning point when considering dwelling types as this period pre-dates the introduction of cavity wall construction. In total, 20% of the occupied housing stock in Scotland was built pre-1919.

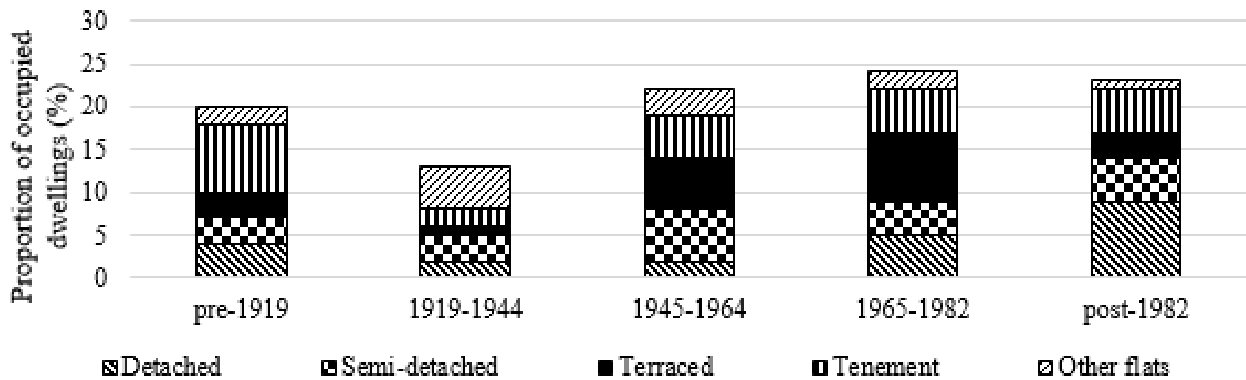

Fig.1. Composition of the Scottish housing stock. Scottish House Condition Survey 2013.

Of the flats built (tenements and 'other flats') in Scotland built pre-1919, 12% are owned and managed by Registered Social Landlords (RSL's) and Housing Associations (Scottish Government, 2013). These organizations are typically not-for-profit, providing rented accommodation to individuals and families on low-income.

This paper documents a project partnership between the Scottish Energy Centre, Historic Scotland and Castle Rock Edinvar Housing Association. The project forms part of the 'Refurbishment Case Study' series produced by Historic Scotland which aims to provide examples of 'best practice' in improving the energy efficiency of traditional (pre-1919) buildings. Historic Scotland are an executive agency of the Scottish Government responsible for protecting the nation's historic environment. Castle Rock Edinvar are an RSL based in Edinburgh and provide housing for over 8000 tenants in more than 6000 homes across 8 local authority areas in Scotland.

J. Bros Williamson. Scottish Energy Centre, Institute for Sustainable construction, 42 Colinton Road, Edinburgh, EH10 5BT. (e-mail: j.broswilliamson@napier.ac.uk).

A. Reid. Scottish Energy Centre, Institute for Sustainable Construction, 42 Colinton Road, Edinburgh, EH10 5BT. (e-mail: al.reid@napier.ac.uk).

J. Stinson. Scottish Energy Centre, Institute for Sustainable Construction, 42 Colinton Road, Edinburgh, EH10 5BT. (e-mail: j.stinson@napier.ac.uk).

J. Currie. Scottish Energy Centre, Institute for Sustainable Construction, Merchiston D59, 10 Colinton Road, Edinburgh, EH10 5DT. (e-mail: j.currie@napier.ac.uk).

II. The energy Efficiency of the Housing Stock

Typically 35% of heat loss is wasted to keep a comfortable internal temperature in solid wall construction typical of many historic housing stock in Scotland (Changeworks, 2008). The primary heating fuel in Scotland's homes is mains gas, which is used to heat 1.9 million homes (78% of the total stock) and 71% of all pre-1919 buildings (Scottish Government, 2013a). Space heating (predominantly gas fueled heating) within the housing stock accounts for over half of energy use in such housing stock (Utley & Shorrock, 2008). The Scottish Government is committed to reducing CO_2 emissions by 80% by 2050 (from a 1990 baseline) with an interim target by 42% in 2020 (Climate Change (Scotland) Act, 2009). If such targets are to be met, this will involve significant readjustment as to the amount of energy consumed in the home (The Scottish Government, 2013b).

In addition to reducing CO_2 emissions, improving the energy efficiency of the housing stock is intended to help reduce instances of fuel poverty. A household is defined as being in 'fuel poverty' if it meets the following criteria: "in order to maintain a satisfactory heating regime (a satisfactory heating regime is defined as: 'Vulnerable' households, 23°C in the living room (zone 1) and 18°C in other rooms (zone 2), for 16 hours in every 24 hour period. For all other households, 21°C in the living room (zone 1) and 18°C in other rooms (zone 2) for 9 hours a day during the week and 16 hours during the weekend), it would be required to spend more than 10% of its income on all household fuel use" (Scottish Government, 2013a). The Scottish House Condition Survey (2013) revealed that in 2013 there were 940,000 households experiencing fuel poverty (39% of all households).

Not all residents in the properties of this study fall under this criteria, however given the building performance of such properties, tenants in different circumstances would struggle to pay the heating bills.

III. The Pilot Properties

As a designated UNESCO World Heritage site located within Scotland's historic capital city, Edinburgh's New Town provides some of the best examples of Victorian and Edwardian neo-classical architecture and urban planning in Scotland. Many of the buildings within the New Town were constructed pre-1919 and as such are labelled 'hard-to-treat' on account of the difficulty of implementing energy saving measures.

The five tenement properties featured in this paper are all good examples of typical pre-1919 construction (see Figure

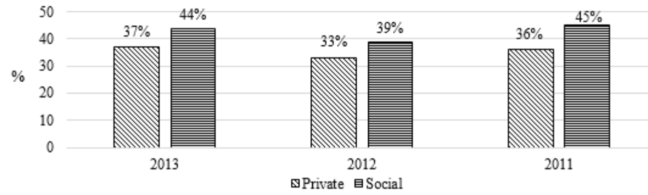

Figure 2. Fuel poverty by tenure. Source: Scottish House Condition Survey 2013.

3.). Externally, the properties are of traditional sandstone construction (solid wall) typically 400 to 600 mm thick (ashlar to the front elevations, rubble to the rear) and natural slate roof coverings. Internally, the properties featured timber floors, timber sash and case windows, timber doors and mainly lath-and-plaster internal linings.

Fig. 3. DSC test at 170ºC curing cycle.

TABLE I
The demonstration properties: key information

	Construction Date	Description	Listed Status	Tenure
Property A	c. 1840	Ground floor tenement flat	Category B	Social rented
Property B	c. 1790	Second floor tenement flat	Category B	Social rented
Property C	c. 1850	First floor tenement flat	Category B	Social rented
Property D	c. 1800	Second floor tenement flat	Category B	Social rented
Property E	c. 1800	First floor tenement flat	Category B	Social rented

The analyzed properties are historically Category B Listed meaning they have been identified by the Planning (Listed Buildings and Conservation Areas) (Scotland) Act 1997 as a building or structure of 'special' interest and is thus awarded protected status. This may apply to an individual building or buildings in a conservation area. There are approximately 48,000 listed buildings in Scotland, arranged in 3 hierarchical categories (A, B and C) representing the relative importance of each building or structure. Critically, listing dictates that any alterations that are deemed to 'affect the character' of the building will require the planning authority to issue 'listed building consent'. The definition of Category B Listing is: 'buildings of more than local importance, or major examples of some particular period, style of building type which may have been altered' (Historic Scotland, 2015). Listed building consent was applied for, and granted for each of the five properties prior to the commencement of the study. Table 1 summarizes the key information for the five properties involved in the study.

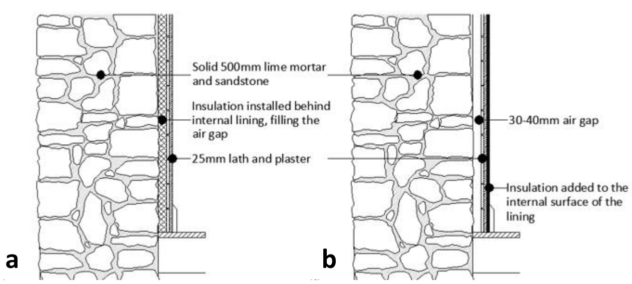

Fig. 4. Internal wall insulation techniques: Insulation blown into cavity (a); rigid insulation applied to internal lining (b).

IV. Summary of Interventions

The interventions summarised below were specifically selected by Historic Scotland because they were deemed to be physically compatible with the existing building fabric (e.g. by not adversely affecting the existing building physics), and also enabled the retention of the existing fabric (e.g. lime plaster on lath finishes).

Two internal wall insulation methods were trialled, as shown in Figure 4.

A. Blown insulation

Two varieties were implemented; an expanded polystyrene bead insulation with a bonding agent, was installed in properties A, B, C and D using a white bead with a thermal conductivity value of 0.040 W/(m·K). In property E a silver bead was used (Figure 5.) with a thermal conductivity value of 0.033 W/(m·K), was installed. Both these systems were pressure pumped behind the internal dry-lining (lath and plaster) in a 30 & 50 mm deep cavity, covering wide expansions of the external walls with the exception of the walls underneath the windows and on the window cheeks where shutters are disclosed.

Fig. 5. Pressurized expanded polystyrene bead insulation in walls.

B. Rigid insulation

Wood fibreboard was specified; however, due to procurement issues, rigid phenolic insulation board was also installed in constrained locations, e.g. below windows where timber finishing's are used, as shown in Figure 6.

Two methods were trialled to improve windows:

A. Aluminium frame secondary glazing

Fitted behind the original single glazed sash and case timber frame are bespoke casement units, manufactured in extruded aluminium, complete with a double glazed unit of an external 6.4 mm laminated glass, 12 mm argon-filled air gap, 6.4 mm laminated low-e (internal pane). The aluminium frame is satin powder coated to match paintwork to timber sash and case window / reveals, and factory applied primer / undercoat to outer timber frame. (see Figure 7 below).

Fig. 6. Rigid insulation on the reveals and under windows.

B. Timber frame secondary glazing (both single and double glazed)

Similarly fitted, were the bespoke casement units in softwood with the timber glazing beads to the opening sash run to match the mouldings on the window sashes. The single-glazed secondary glazed units were made up with 6.4 mm laminated glass. The double-glazed secondary glazed units were made up with 4 mm float glass, 16 mm argon-filled gap and 4 mm toughened low-e (internal pane). The units were made up in the workshop with fitted ironmongery and pre-painted with one coat of undercoat primer and one coat gloss, and delivered on site fully glazed, for final paint coat on completion of installation.

V. Testing Methodology

Measuring the thermal transmittance, or U-value, provides a comparable measure of the thermal performance of a building component. The U-value is defined in ISO 7345:1996 as the "heat flow rate in the steady state divided by the area and the temperature difference between the surroundings on each side of a system". The unit of measurement is watts per meter squared degree Kelvin (W/m²K).

Fig. 7. Secondary aluminium windows behind existing sash & case timber windows.

As a means of recognising the improvement value of the refurbishment methods; in-situ U-value measurements were undertaken using the guidance set out in ISO/DIS 9869-1:1994 Thermal insulation, Building elements, In-situ measurement of thermal resistance and thermal transmittance - Part 1: Heat flow meter method, (now BS ISO 9869-1:2014). This established methodology is endorsed by experienced practitioners such as Baker (2008, 2011) and Rye (2011).

The in-situ U-values were measured using thermopile-based heat flux transducers (Hukseflux HFP01) of 80 mm diameter and 5 mm thickness, providing a typical accuracy of ±10%. In addition, K-type thermocouples were used to record temperatures, connected to Grant Squirrel data loggers with 24 bit A-D conversion resolution. As a precautionary action, additional temperature and humidity Tiny Tag loggers of a typical accuracy of ±0.3°C were used to measure internal and external conditions. The testing equipment is shown in Figure 8 and Figure 9 where equipment is installed.

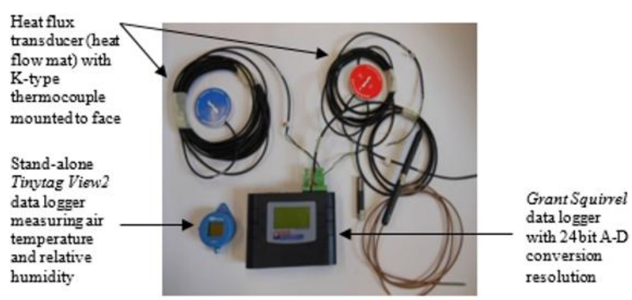

Fig. 8. The testing equipment.

The pre and post-intervention testing periods are shown in Table 2. In the case of Property D, two separate periods of post-intervention testing were undertaken due to additional improvements introduced in latter stage.

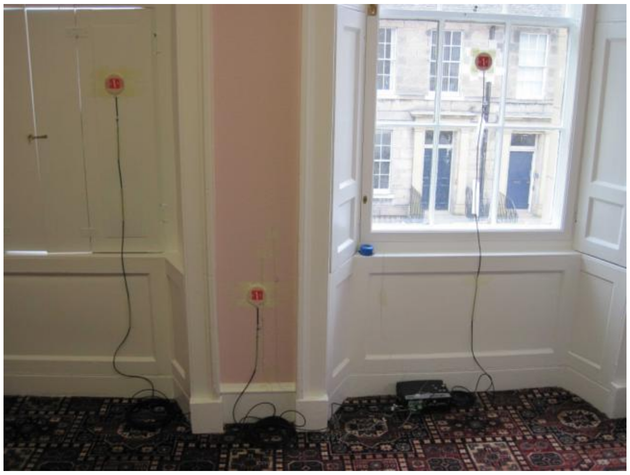

Fig. 9. In-situ test equipment on walls and windows.

No tenant decanting took place, therefore in each property, care was taken to ensure a tidy working environment and the protection of home contents from dust etc. As such, loose floor coverings and curtains were taken down and stored out-with the main working areas. In addition, any fitted carpets were rolled back and all items remaining in the room were covered in dust sheets. Protective flooring (both polythene and hardboard) was installed around the working areas and access routes. Upmost care was undertaken in the removal of original building elements, which were taken down by hand, indexed and safely stored prior to reinstatement.

VI. Results

The pre and post-intervention U-value results for the walls are shown in Table 3. Blown insulation was trialled in 4 instances, with each providing a U-value reduction (ranging from 20% to 50%). Rigid insulation (rigid phenolic insulation board) was installed and tested in 5 instances, providing a significant U-value reduction (ranging from 71% to 81%).

The pre- and post-intervention U-value results for the window interventions are shown in Table 4. The timber secondary units, both double and single glazed, were each trialled in 1 property. In both cases the U-value was significantly reduced as a result (single glazed: 71% average reduction, double glazed: 88% average reduction). The aluminium double glazed secondary unit was trialled in 1 property, providing an average 85% reduction in the U-value.

Figure 10 considers each of the five interventions tested by the (average) U-value reduction (%). As can be seen, the most effective intervention was found to be the timber double glazed secondary unit, which provided an 88% U-value reduction. The least effective solution was the blown insulation (expanded polystyrene bead insulation with bonding agent), which still provided a 40% U-value reduction.

TABLE II
Pre and post-intervention testing periods

	Pre-intervention testing period	Post-intervention testing period
Property A	20/10/2010 – 05/11/2010	29/03/2011 – 12/04/2011
Property B	20/10/2010 – 05/11/2010	01/02/2011 – 22/02/2011
Property C	20/10/2010 – 05/11/2010	28/01/2011 – 22/02/2011
Property D	20/10/2010 – 05/11/2010	28/01/2011 – 22/02/2011 12/04/2011 – 27/04/2011
Property E	17/02/2011 – 25/02/2011	28/03/2011 – 12/04/2011

TABLE III
Walls; pre and post intervention U-value results

	Intervention	Monitored U Value (W/m²K)	
		Pre-intervention	Post-intervention
Property A	Expanded polystyrene bead insulation with bonding agent	1.4	0.8
	Rigid phenolic insulation board	1.9	0.4
Property B	Expanded polystyrene bead insulation with bonding agent	0.5	0.4
	Rigid phenolic insulation board	0.7	0.2
Property C	Expanded polystyrene bead insulation with bonding agent	1.4	0.7
	Rigid phenolic insulation board	1.6	0.4
Property D	Expanded polystyrene bead insulation with bonding agent	1.3	0.7
	Rigid phenolic insulation board	1.6	0.3
	Rigid phenolic insulation board	1.5	0.4

TABLE IV
Windows: pre and post intervention U-value results

	Intervention	Monitored U Value (W/m^2)	
		Pre-intervention	Post-intervention
Property A	-	-	-
Property B	Aluminium double glazed secondary unit	5.4	0.8
Property C	-	-	-
Property D	Timber double glazed secondary unit	5.2	0.6
Property E	Timber single glazed secondary unit	5.2	1.5

VII. Conclusions

This study involved trialling a number of interventions with the aim of improving envelope thermal performance (and thus energy efficiency) in pre-1919, Category B listed, traditionally-constructed tenement flats in Edinburgh's New Town. In testing five different interventions, the results demonstrated a reduction in the U-value of between 40% - 88% on the elements (walls and windows) tested during the study. The results are significant as each of the interventions was approved by Historic Scotland, in reference to the stringent criteria that is placed on alterations to Listed Buildings in Scotland.

This paper has provided further evidence of effective solutions that can help reduce energy consumption in the home. The wide-scale implementation of such measures – a so-called mass-retrofit - would not only help Scotland meet its carbon emission targets but would also help many households to escape the adversity and indignity of fuel poverty.

Acknowledgment

The authors are grateful for the support provided by Historic Scotland Conservation Directorate and Castle Rock Edinvar Housing Association in undertaking this study. For further information on the refurbishment of historic buildings please visit the Historic Scotland website: http://www.historic-scotland.gov.uk/refurbcasestudies.

References

Baker, P. (2008) Historic Scotland Technical Paper 2: In situ U-value measurements in traditional buildings: preliminary results, Historic Scotland, Edinburgh

Baker, P. (2011) Historic Scotland Technical per 10: U-values and traditional buildings: in situ measurements and their comparisons to calculated values, Historic Scotland, Edinburgh

Boardman, B. (2007) Home Truths: A low-carbon strategy to reduce UK housing emissions by 80% by 2050. Oxford's Environmental Change Institute. A research report for The Co-operative Bank and Friends of the Earth, University of Oxford.

BS EN ISO 7345:1996: Thermal insulation: physical quantities and definitions. (Identical with 1987 ed.) London: BSI.

BS ISO 9869-1:2014 Thermal insulation, Building elements, In-situ measurement of thermal resistance and thermal transmittance - Part 1: Heat flow meter method. London: BSI

Changeworks (2008) Energy Heritage: A guide to improving energy efficiency in traditional and historic homes. Edinburgh, Changeworks Resources for Life.

ISO/DIS 9869-1:1994 Thermal insulation, Building elements, In-situ measurement of thermal resistance and thermal transmittance - Part 1: Heat flow meter

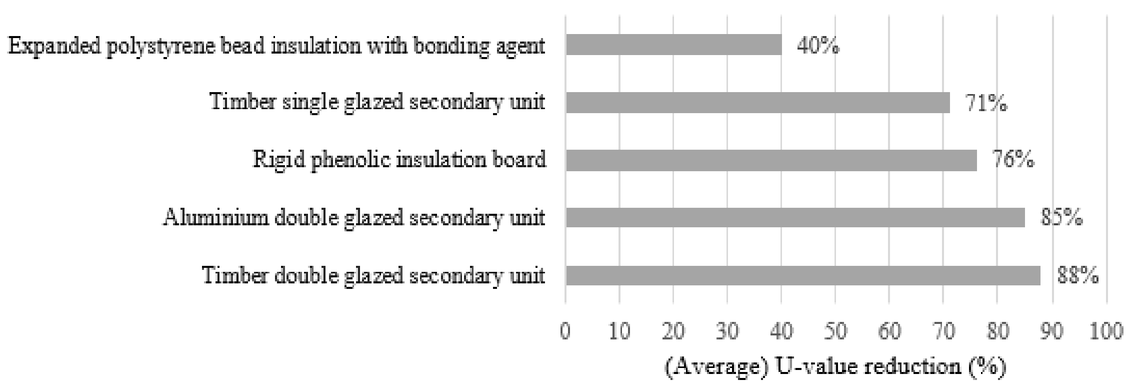

Fig. 10. Average U-value saving for each intervention.

method. London: BSI

Historic Scotland (2015) Listed Building definitions and data. Available at: http://www.historic-scotland.gov.uk/index/heritage/historicandlistedbuildings/listing.htm

Rye, C. (2011) U-value report (SPAB Research Report, revised edition), SPAB, London

The Scottish Government (2002) Scottish Fuel Poverty Statement, Scottish Government, Edinburgh.

Available at: http://www.gov.scot/Resource/Doc/46951/0031675.pdf

The Scottish Government (2009) Climate Change (Scotland) Act 2009. Crown Copyright 2009, Scotland, UK.

The Scottish Government (2013a) Scottish House Condition Survey – Key Findings 2013, Scottish Government, Edinburgh. Available at: http://www.gov.scot/Resource/0046/00465627.pdf

The Scottish Government (2013b) Low Carbon Scotland: Meeting our Emissions Reduction Targets 2013-2027: RPP2. Edinburgh.

Utley, J.I. & Shorrock, L.D. (2008) Domestic energy fact file 2008. London.